

Asymmetry in the decay $\Omega^- \rightarrow \Xi^- \gamma$

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Abstract

We consider the asymmetry in the decay $\Omega^- \rightarrow \Xi^- \gamma$ assuming that a Vector Meson Dominance approach for the $s \rightarrow d \gamma$ transition gives the dominant contribution. Since in this long-distance approximation the decay is due to a single quark transition $s \rightarrow d \gamma$, the angular distribution asymmetry is given by the single positive asymmetry parameter $\alpha_h = \frac{M_s^2 - M_d^2}{M_s^2 + M_d^2} = 0.4 \pm 0.1$. We also discuss the asymmetry in $\Xi \rightarrow \Sigma^- \gamma$, which is expected to be between -0.2 and 0.3.

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The process $\Omega^- \rightarrow \Xi^- \gamma$ has a special place [1-4] among hyperon radiative decays, since the quark composition of the participating hadrons precludes W-exchange among pairs of valence quarks to induce this decay. A similar situation occurs in $\Xi^- \rightarrow \Sigma^- \gamma$ decay. Accordingly, these decays have been singled out [2] as possible candidates for the detection of the single quark $s \rightarrow d \gamma$ magnetic transition. Using the present knowledge on the QCD-corrections to the effective nonleptonic Hamiltonian, the short-distance electroweak penguin contribution to these rates [1,5,6] turns out to be lower by about two orders of magnitude than the present experimental upper limit on the Ω^- decay rate ($\Gamma_{\text{exp}}^{\Omega^- \rightarrow \Xi^- \gamma} < (3.7 \cdot 10^{-9} \text{eV})$ [7]) and lower by about one order of magnitude than the experimental value for $\Xi^- \rightarrow \Sigma^- \gamma$ ($\Gamma_{\text{exp}}^{\Xi^- \rightarrow \Sigma^- \gamma} = (5.10 \pm 0.92) \cdot 10^{-10} \text{eV}$ [8]). A similar result is given by the calculation of gluonic penguins [9,10]. Turning to long-distance contributions, the structure of the nonleptonic $\Delta S = 1$ Hamiltonian does not induce pole contributions in the $\Omega^- \rightarrow \Xi^- \gamma$ decays. Kogan and Shifman [1] have calculated the two-particle intermediate “s-channel” contributions to radiative decays of hyperons. For the decay $\Omega^- \rightarrow \Xi^- \gamma$ they found $\Gamma_{\text{“s-channel”}}^{\Omega^- \rightarrow \Xi^- \gamma} \simeq 10^{-10} \text{eV}$. Thus, the “s-channel” contributions are lower than the present experimental limit by a factor of about 40. For the decay $\Xi^- \rightarrow \Sigma^- \gamma$ their result is of the same order as the present experimental value. On the other hand, a Vector Meson Dominance (VMD) approach to hyperon radiative decays on the hadronic level [11], which uses $SU(6)_W$ -symmetry to determine the parity-violating couplings of vector mesons to baryons from nonleptonic hyperon decays, finds a branching ratio for $\Omega^- \rightarrow \Xi^- \gamma$ which is already slightly

higher than the experimental limit.

A different approach [12] for calculating the long-distance contribution, using a VMD approximation for the $s \rightarrow d\gamma$ transition (along the lines discussed by Deshpande et al. [13] for $b \rightarrow s\gamma$), shows that this contribution can be of the order of the present experimental limit.

The $s \rightarrow d\gamma$ amplitude in the VMD approximation is [12]

$$A_{\text{VMD}} = e \frac{G_F}{\sqrt{2}} \sin \theta_c a_2(m_s^2) C_{\text{VMD}} \frac{1}{M_s^2 - M_d^2} \bar{d} \sigma^{\mu\nu} [M_s R - M_d L] s F_{\mu\nu} , \quad (1)$$

$$C_{\text{VMD}} = \frac{2}{3} \sum_i \frac{g_{\psi_i}^2(0)}{m_{\psi_i}^2} - \frac{1}{2} \frac{g_\rho^2(0)}{m_\rho^2} - \frac{1}{6} \frac{g_\omega^2(0)}{m_\omega^2} , \quad (2)$$

where $\sin \theta_c = 0.22$, $a_2(m_s^2) \geq 0.5$ is a phenomenologically determined QCD coefficient, and g_V^2 are the couplings of vector mesons to photons. Due to the nature of the VMD approximation, M_s and M_d should correspond to “constituent” mass parameters.

The rate of the Ω^- radiative decay induced by the $s \rightarrow d\gamma$ transition of Eq. (1) is [12,14,15]

$$\Gamma^{\Omega^- \rightarrow \Xi^- \gamma} = \frac{16\alpha G_F^2}{3} \left(\frac{m_{\Xi^-}}{m_{\Omega^-}} \right) |\vec{q}|^3 \sin^2 \theta_c a_2^2 C_{\text{VMD}}^2 \frac{M_s^2 + M_d^2}{(M_s^2 - M_d^2)^2} \quad (3)$$

where \vec{q} is the photon momentum in the Ω^- rest frame.

The large theoretical uncertainty of over 40% in the value of the sum $\sum_i \frac{g_{\psi_i}^2(0)}{m_{\psi_i}^2}$ which appears in C_{VMD} , would allow the VMD contribution to saturate the experimental bound. In fact, the experimental limit on the decay rate $\Omega^- \rightarrow \Xi^- \gamma$ can be used to constrain $|C_{\text{VMD}}| < 0.01 \text{GeV}^2$ [12].

From Eq. (1) it follows that on the quark level the angular distribution has the form

$$\frac{1}{\Gamma^{s \rightarrow d\gamma}} \frac{d\Gamma^{s \rightarrow d\gamma}}{d(\cos \theta)} = \frac{1}{2}(1 + \alpha_h \cos \theta) \quad (4)$$

where

$$\alpha_h = \frac{M_s^2 - M_d^2}{M_s^2 + M_d^2} = 0.4 \pm 0.1 \quad (5)$$

Here θ is the angle between the spin of the s quark and the direction of the three-momentum of the d quark. This functional form for α_h is valid for the short-distance as well [4,16], but in this case one uses current quark masses to obtain $\alpha_h \simeq 1$.

The angular distribution for the radiative decay $\Omega^- \rightarrow \Xi^- \gamma$, when we take into account all possible contributions to this decay, is proportional to $(\alpha_0 + \alpha_1 \cos \theta + \alpha_2 \cos^2 \theta + \alpha_3 \cos^3 \theta)$. But it turns out [14,15] that the angular distribution of the decay rate $\Omega^- \rightarrow \Xi^- \gamma$, when it is going through a single quark transition $s \rightarrow d\gamma$, is given by the same single asymmetry parameter α_h of eq. (4) and has the following form [14,15]

$$\frac{1}{\Gamma^{\Omega^- \rightarrow \Xi^- \gamma}} \frac{d\Gamma^{\Omega^- \rightarrow \Xi^- \gamma}}{d(\cos \theta)} \Big|_{s_z^\Omega = 3/2} = \frac{3}{8}(1 + 2\alpha_h \cos \theta + \cos^2 \theta) \quad (6)$$

$$\frac{1}{\Gamma^{\Omega^- \rightarrow \Xi^- \gamma}} \frac{d\Gamma^{\Omega^- \rightarrow \Xi^- \gamma}}{d(\cos \theta)} \Big|_{s_z^\Omega = 1/2} = \frac{5}{8}\left(1 + \frac{2\alpha_h}{5} \cos \theta - \frac{3}{5} \cos^2 \theta\right) \quad (7)$$

where θ is the angle between the direction of the outgoing baryon Ξ^- and the z axis, and $s_z^\Omega = 3/2, 1/2$ are the projections of the spin of Ω along the z axis.

As it is noted in ref. [14] the decay rate of $\Xi^- \rightarrow \Sigma^- \gamma$ has the same form for the angular distribution as the quark decay $s \rightarrow d \gamma$ eq. (4) i.e. $(1 + \alpha_h \cos \theta)$. But in the decay $\Xi^- \rightarrow \Sigma^- \gamma$ there are two types of contributions to the asymmetry parameter as well as to the decay rate. The long-distance $s \rightarrow d \gamma$ contribution to the rate is $\Gamma_{\text{VMD}}^{\Xi^- \rightarrow \Sigma^- \gamma} < 4.4 \cdot 10^{-10} \text{eV}$ [12], while the two particle “s-channel” contribution is $\sim 5 \cdot 10^{-10} \text{eV}$ [1,17]. Taking $C_{\text{VMD}} = 0.01$ and the particle loop contribution as in Ref. [17] we find $-0.2 < \alpha_h < 0.3$, the range being the result of the unknown phase between the two contributions. By decreasing C_{VMD} to zero, α_h is kept in the above range but the branching ratio becomes somewhat too large.

To summarize, we predict a positive asymmetry equal to 0.4 ± 0.1 for the decay $\Omega^- \rightarrow \Xi^- \gamma$, based on the $s \rightarrow d \gamma$ VMD approach of ref. [12]. For the decay $\Xi^- \rightarrow \Sigma^- \gamma$ we predict an asymmetry in the range -0.2 and 0.3 . We urge the measurement of these asymmetry parameters which will hopefully elucidate the nature of the $s \rightarrow d \gamma$ transition and its role in hyperon radiative decays.

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